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Impact of Abiotic, Biotic, and Anthropogenic Factors on the Spread of *Salmonella* in the Food Industry and Aquaculture Systems

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Salmonellosis, caused by bacteria of the genus Salmonella, poses a significant global public health and economic challenge, resulting in annual losses estimated at $1–3 billion. Despite existing control measures, *Salmonella* prevalence remains high due to its complex and cyclical spread involving multiple transmission routes. This review systematically identifies and analyzes the roles of abiotic (e.g., water, soil), biotic (e.g., animal hosts, microbiota), and anthropogenic (e.g., feed, hygiene practices) factors in the dissemination of *Salmonella* within the food industry and aquaculture. By synthesizing current epidemiological and ecological knowledge, this study highlights that an integrated, multi-source approach, rather than isolated interventions, is critical for effective *Salmonella* control. The findings underscore the interconnectedness of *Salmonella* reservoirs and transmission pathways, providing a theoretical basis for developing comprehensive and sustainable strategies to reduce its prevalence, thereby enhancing food safety and public health globally.

Keywords: *Salmonella*, Salmonellosis, Salmonellosis control measures, Feed additives, Aquaculture, Feeds, Bacteriocins.

INTRODUCTION

Long-lasting research on epidemiology and ecology is still relevant today, providing new information about various existing infectious diseases. One of the most widespread and dangerous bacteria is *Salmonella* (Punchenko et al., 2022). Salmonella is a genus of bacteria represented by numerous serotypes that vary significantly in their pathogenicity in humans. Some cause severe systemic infections, while others result in relatively mild foodborne illnesses (Li et al., 2025; Peroutka et al., 2025; Quiñones et al., 2025). Despite these differences, Salmonella remains one of the most common causes of acute gastrointestinal infections worldwide (Awal et al., 2016; Polyanin et al., 2023). In some cases, salmonellosis can become systemic, spreading beyond the intestine and leading to severe systemic infections such as sepsis, meningitis, or endocarditis. Multidrug-resistant Salmonella strains, resistant to multiple classes of antibiotics, pose a particular threat (Ampleeva et al., 2024; Hempstead et al., 2025; Soffritti et al., 2025). They are often associated with systemic infection and high mortality rates, significantly limiting the possibilities of effective therapy (Ampleeva et al., 2024). The disease develops when the pathogen or its toxins enter the gastrointestinal tract, causing increased motility of the neuromuscular system of the stomach and intestines (Edache et al., 2024). This leads to the characteristic abdominal cramps and hyperperistalsis, as well as alteration of the physicochemical properties of the intestinal contents. As a result, intestinal dysbiosis may develop, especially in people with pre-existing digestive disorders, a weakened immune system, or improper use of antibiotics (Li et al., 2025; Mineeva, 2024).

Currently the main source of the salmonellosis spread is food from animal raw materials. The food industry and aquaculture systems serve as major interfaces between animal production and human consumption, making them critical control points in the transmission of *Salmonella*. Identifying key infection routes and environmental triggers is vital for developing effective prevention strategies. In addition, this industry shows great interest in researching the spread of *Salmonella* bacteria in order to prevent possible diseases and protect public health. The annual economic damage from salmonellosis worldwide is estimated at 1-3 billion dollars (Omarov & Mayorova, 2024). *Salmonella* serotypes vary in

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pathogenicity and host specificity, with some strains more likely to cause severe illness in humans than others. They are widespread all over the world and are one of the most common causes of foodborne infections. Studies (Mohammad & Md, 2024) have shown that the sources of salmonellosis spread in animal husbandry are infected water, soil, feed, and *Salmonella* - carrying animals themselves, including rodents and wild birds. However, human-driven factors such as poor sanitation, overcrowded farming conditions, and inadequate food handling further amplify the spread. The global surge in *Salmonella* cases is due to increased consumption of foods that are extremely sensitive to bacterial contamination, such as raw eggs, meat and dairy products, as well as inadequate hygiene on farms and in residential areas, which contributes to the spread of bacteria. A large number of studies are devoted to the fight against salmonellosis in poultry farming, since this area is the most likely to spread and become infected. Of all outbreaks of foodborne infections in the world, more than 45% are attributed to salmonellosis, of which 34% is associated with the consumption of chicken meat (Omarov & Mayorova, 2024*)*. When infected with salmonellosis, poultry has characteristic signs of the disease: decreased feed intake, lethargy, conjunctivitis, corneal opacity, and others Darovskikh (2023). Without appropriate treatment, there are large losses of birds. Therefore, when these symptoms are detected, they immediately resort to treatment. In addition to birds, pigs and cattle suffer from salmonellosis (Omarov & Mayorova, 2024*)*. Despite numerous studies in this field (Davies & Wray, 1997; Koptev et al., 2019; Alieva, 2020; Tyurin et al., 2021; Litvinova, 2022; Makhmudov et al., 2022; Muckey et al., 2022; Satkeeva et al., 2022; Zagainova et al., 2022; Porto et al., 2023; Mishra et al., 2024). As well as measures to reduce the spread of *Salmonella*, the prevalence of *Salmonella* and outbreaks of salmonellosis in both animals and people who consume contaminated products remains high in various countries. In comparison with poultry farming, as well as pig and cattle breeding, less importance is given to aquaculture facilities, since they do not suffer from salmonellosis, but they are carriers of a pathogenic microorganism. In addition, exposure to only one of the transmission sources of Salmonella spread is water, soil, feed, and animals (Shvets et al., 2022; Porto et al., 2023; Marchenko et al., 2024; Mohammad & Md, 2024; Aishwarya et al., 2025; El-Saadony et al., 2025; Villeta et al., 2025) it does not significantly reduce the scale of its spread and harm, both from the point of view of safety and health of humans and animals, and from an economic point of view, since the distribution process is cyclical, which thereby increases the speed and volume of its spread. In connection with the abovementioned information, this study aims to synthesize current knowledge to identify the key abiotic, biotic, and anthropogenic factors driving *Salmonella* spread within the food industry and aquaculture, and to propose an integrated approach for its reduction.

MATERIALS AND METHODS

***Literature search and selection criteria*:** The foundation of the study was formed by the scientific works of leading specialists in the occurrence and spread of salmonellosis sector. The methodological basis of the article relies on statistical methods and qualitative content analysis of scientific literature.

The article is of a review nature and primarily raws upon scientific articles on relevant topics. At the first stage, we searched for scientific materials using the following keywords in article titles: “Salmonella”, “fighting salmonellosis”, “salmonellosis", “aquaculture”, “poultry”, “animal husbandry”, “farming”, “feed”, “feed additives”, “antibiotics” – both individually and in various combinations. This search yielded approximately 200 scientific works on the topic. At the second stage, the abstracts of the selected articles were analyzed to filter out works unrelated to the research topic.

After this step, 90 articles remained. In the third stage, a fulltext analysis of the articles was performed to ensure complete alignment with the study’s focus. Following this step, 35 articles were included in the final research sample.

***Databases consulted*:** A thorough literature search was conducted using several academic databases. Literary sources were searched in abstract and information databases, including eLibrary, the Russian State Library, Science Direct, Research Gate, Google Scholar, National MedLine and others.

***Criteria applied*:** To identify the problems of *Salmonella* spread and ways to reduce their growth, 4 main sources of spread are considered: water, soil, feed and animals. Particular attention is paid to aquaculture, since aquatic organisms do not suffer from salmonellosis and are less considered by the scientific community as one of the sources of the spread of salmonellosis. A comprehensive assessment of the spread of *Salmonella* in 4 groups has been carried out and ways to solve the problem of the spread of *Salmonella* in the agro-industrial complex have been identified.

RESULTS

***Water*:** For many years, it has been assumed that humans or animals are the main source and carrier of microorganisms capable of causing infectious diseases. Over time, various studies in the field of epidemiology have helped to establish the consequence that the reproduction of pathogenic microbes is also active in the external environment. Temperature, water activity, hydrostatic pressure, and oxygen availability are just some of the abiotic factors that can affect the reproduction of infectious bacteria (Shvets et al., 2022; Howard et al., 2024).

Biotic factors are considered to be natural conditions and living organisms – various types of animals, especially birds and reptiles, which can be carriers of *Salmonella* and spread it through contact. Another important factor is the environment microflora, which creates conditions for the reproduction of bacteria.

Do not forget that human activities related to the production, processing and sale of food products, as well as violations of hygiene rules in food-related enterprises, farms and food storage, contribute to the development and reproduction of salmonellosis bacteria. Scientists (Golovko et al., 2024) conducted a review of modern approaches to determining the presence of *Salmonella* bacteria in aquatic biogeocenoses. The presence of this type of bacteria has been found in many water bodies. The study of salmonellosis and its transmission routs is very important, as about 94 million cases of gastroenteritis caused by this infection and about 155 thousand fatal cases have been identified (Majowicz at al., 2010; Golovko et al., 2024). The main source of intestinal pathogens in surface waters is wastewater that has been insufficiently treated. If no control and prevention measures are taken, the risk of infection remains high and may lead to more frequent epidemics. When irrigating agricultural fields, there is a high risk that pathogens will be transmitted to humans through food. It is important that when food is consumed raw (without heat treatment), the risk of contracting the infection in question increases several times.

Causes: The main focus of the scientific work (Golovko et al., 2024) was on aquaculture. It is important to note that fish farming, today, is a strategically significant and rapidly developing branch of the agro-industrial complex. In the context of a steady trend towards the intensification of technological processes in aquaculture, correlating with an increased epizootological risk of bacterial infections in aquatic organisms, systematic monitoring of the ecological and epidemiological circulation of *Salmonella* at all technological stages is becoming an imperative requirement for biosafety. At low temperatures, *Salmonella* bacteria can remain viable in water for a long time, up to 5 months (Omarov & Mayorova, 2024). This phenomenon is associated with the peculiarities of their physiology: slowing down of metabolic processes with a decrease in temperature, which creates conditions for long-term survival in the environment. Under such conditions, the bacteria do not die, but pass into a state of metabolically reduced activity or sleeper (spirilized forms), resistant to extreme environmental conditions (Marchenko, 2024). Like the soil cover, aquatic ecosystems represent a natural niche for the existence of numerous pathogenic strains. These microorganisms successfully adapt to various aquatic environments, from open water areas to deep groundwater (Shvets et al., 2022). The long-term existence of Salmonella in water increases the risk of infection of aquatic organisms such as fish and aquatic invertebrates. Infection occurs when fish come into contact with polluted water, especially in reservoirs that receive wastewater that contains pathogenic microorganisms. *Salmonella* water pollution often occurs through the ingestion of fecal matter containing pathogenic *Salmonella* bacteria (Torikov et al., 2012). The main sources of such pollution are sewage waste, animal farm discharges, human settlements, and uncleaned sewage. When these polluted waters enter natural reservoirs, bacteria enter the surrounding water and can spread through the ecosystem. Therefore, fecal contamination of water with *Salmonella* is a serious problem that requires appropriate sanitary control and cleaning of reservoirs. As a result, aquatic ecosystems polluted by wastewater become a source of long-term infection, and their treatment requires special measures to reduce the risk of bacterial pathogens spreading and the cultivation of safe aquaculture products (Torikov et al., 2012).

***Control measures*:** The conducted analytical review of scientific publications (Shadrova et al., 2022) makes it possible to systematize data on methods of the salmonellosis microbiological diagnosis in aquaculture facilities. These approaches make it possible to successfully isolate living *Salmonella spp.* cells, after which they can be serotyped, their virulent characteristics, such as the ability to form biofilms, and determine resistance and sensitivity to antimicrobial agents (Shadrova et al., 2022). To ensure the safety of aquatic organisms, in conditions of anthropogenic impact, it is necessary to implement a multi-level system of protective measures. It is of paramount importance to limit the ingress of harmful compounds into water bodies, which is achieved by improving technological processes in industrial plants. Regulation of agrochemicals' use requires special attention, since their movement with surface runoff poses a serious threat to aquatic ecosystems. The introduction of the organic farming principles and precision farming technologies can significantly reduce the chemical load on reservoirs. Various methods of processing and disposal of agricultural waste prevent irreparable damage to the environment (Marchenko, 2024).To combat pathogenic microorganisms, including salmonella, antibiotics are widely used, the negative effects of which have long been known: antibiotic resistance, allergic reactions among people who consume water from aquaculture facilities that contain antibiotics, the economic costs of cleaning water contaminated with antibiotics, etc. Therefore, the use of probiotic drugs is increasingly being considered to combat pathogenic microorganisms (Khmyrov A.V. et al., 2013; Nasonkina & Markin, 2017), which, as a result of the activation of biochemical self-purification processes, accelerates the death of pathogenic microorganisms in water. Most of these probiotic drugs have a broad spectrum of action, which may not always affect, for example, *Salmonella* and lead to its death. Therefore, the development of specialized probiotic drugs, as well as probiotic drugs, is an urgent area of research in order to reduce the prevalence of *Salmonella* in the aquatic environment.

Soil: Soil is an important habitat for a variety of microorganisms, including pathogenic ones (Shvets et al., 2022) Bacteria from the genus Salmonella can enter the soil in various ways. They often get there through the feces of infected animals or humans. Bacteria can also enter through dirty water, fertilizers containing contaminated food residues or animal waste. *Salmonella* can remain viable in the soil (Omarov & Mayorova, 2024) for a long period of up to 1.5 years. This is a serious problem because the soil plays a key role in the ecological cycle and can serve as a reservoir of infection. The connection between soil and water is important because microorganisms, including salmonella, easily move and spread through waterways, especially in the presence of sediments that pollute water bodies.

Thus, soil and water form a single system in which the microbiological balance and the quality of the environment can significantly affect the spread and preservation of pathogens.

***Causes*:** The circulation of the disease under study is quite primitive: bacteria from the soil can enter plants or be reintroduced to animals or humans, causing new cases of the disease. In the soil, bacteria can remain viable, especially under suitable conditions – heat and high humidity. The work devoted to the study of environmental factors contributing to the persistence of certain pathogens in the soil, including *Salmonella*, describes quite accurately the ways pathogens enter agricultural lands (Alieva, 2020). The application of manure or compost to the soil is a widespread agricultural practice. However, to date, there are no clear regulations regarding the methods of using manure in the cultivation of agricultural products to reduce the risk of foodborne diseases (Tyurin et al., 2021).

Pathogens of various infectious diseases, including salmonellosis, can spread in the soil (Fisunova & Vishnevskaya, 2022). It is important to note that bacteria of the genus *Salmonella* can enter the soil along with feces, urine, nasal mucus and saliva of an infected living organism even after many years (Zagainova et al., 2022; Omarov & Mayorova, 2024). As a result, bacteria can persist in the soil, creating a risk of infecting animals and even humans with further contact or consumption of plants grown on such soil. Therefore, it is vital to examine the soil and monitor its biological purity. First of all, in order to prevent the spread of bacteria and prevent the emergence of new epidemics. Soil protection helps to preserve human and animal health, as well as prevent economic losses.

***Control measures*:** Special attention is paid to ensuring the microbiological safety of organic fertilizers – manure and compost, which is achieved through their special treatment and storage in optimal conditions. Studies (Tyurin et al., 2021) have shown that biotechnological methods of processing organic livestock waste, such as active aerobic oxidation (accelerated composting) and anaerobic digestion in bioenergy plants, play a key role in ensuring sanitary safety and environmental cleanliness (Tyurin et al., 2021).

In Aishwarya et al. (2025) the resistance of the *Salmonella* bacterium during the cultivation of microgreens was investigated. Seeds of daikon microgreens, mustard, broccoli and red cabbage were infected with pathogens (including salmonella). Subsequently, samples of the substrate on which the cultivation took place, as well as edible parts of the microgreens, were analyzed. During the experiment, patterns of *Salmonella* survival over a 14-day period were traced, which showed: The type of substrate significantly affects the survival of pathogens. This study Aishwarya *et al*. (2025) highlights the importance of ensuring microbiological safety not only at the stage of seed preparation for cultivation, but also at all stages of food production, including the analysis of the soil on which plants will be grown. Microbial control helps prevent possible contamination and the development of pathogenic bacteria such as *Salmonella* in finished products, which is important to protect consumer health and comply with sanitary standards. Constant monitoring and preventive measures can significantly reduce the risks associated with microbiological safety in agriculture and food production.

***Animals and their processed products*:** The spread of salmonellosis in animals occurs through various methods, such as direct contact with infected individuals, indirect interaction with the environment, as well as through feed that may be contaminated with salmonella. It is highly significant to prevent salmonellosis in farm animals, as this, first of all, helps to preserve their health, thereby preventing pathogens from entering the human body. If measures are not taken in time, the disease can spread rapidly throughout the household, and it will become more difficult and expensive to deal with it (Khishov et al., 2023). Darovskikh I.A. (Darovskikh, 2023) analyzed the existing factors in the spread of salmonellosis both in poultry farms and among the population. They demonstrate a relatively stable situation in the registration of cases and their total number. The article also examines the role of the environment and poultry products as factors capable of directly transmitting infection. Bacteria of the genus *Salmonella* have been found both in environmental objects and in the biological material of dead birds.

***Causes*:** As a result of the study (Darovskikh, 2023), the degree of contamination of various poultry products with *Salmonella* was determined and its role in the epidemiological situation was shown. It has been proven that the most common causative agent of salmonellosis appears in unprocessed poultry products. This type of product usually includes: internal organs of poultry, raw materials from fat, skin, bones and other offal. Eggs, being an essential component of the food industry and cooking, often become a factor in the transmission of the pathogen. Laboratory studies of samples of chicken eggs and products containing them demonstrate a high frequency of contamination by bacteria of the genus *Salmonella enterica* (Darovskikh, 2023).

Environmental pollution, including contamination of soil, water and feed with pathogenic bacteria such as salmonella, contributes to the infection of birds. Unsatisfactory sanitary conditions in poultry houses and poultry complexes, as well as the use of dirty tools and equipment, increase the risk of infection. Contact with wild birds or other animals also increases the likelihood of infection, especially in case of violations of feeding conditions, such as insufficient processing of feed, violation of its storage standards, which creates a favorable environment for the development of bacteria (Darovskikh, 2023).

***Control measures*:** Salmonellosis is an infectious disease caused by bacteria of the genus *Salmonella* that infect agricultural, domestic and wild animals. The main objects are birds, pigs, cattle and rodents. This infection occurs in an alimentary manner, through contaminated feed, water, or contact with infected individuals. The fight against salmonellosis is complicated by the high resistance of bacteria in the external environment and the development of antibiotic resistance. In this regard, systems of preventive measures for salmonellosis of farm animals and birds are especially important, taking into account the regional characteristics of the epizootic process (Litvinova, 2022). Vaccination is one of the key methods for controlling salmonellosis, providing specific protection for animals by stimulating the immune response. Several types of vaccines are used in veterinary practice, differing in composition and mechanism of action (Makhmudov et al., 2022). Inactivated (killed) vaccines contain whole bacterial cells treated with chemical or physical methods; they induce predominantly humoral immunity, contributing to the production of antibodies. Live attenuated vaccines based on weakened strains of *Salmonella* provide more comprehensive protection by stimulating both humoral and cellular immunity, and can also be administered orally, which simplifies mass vaccination. Various diagnostic methods are used to detect *Salmonella* infection in animals at an early stage. One of the most common is the bacteriological examination of samples, such as feces, blood or tissues, in order to detect the presence of *Salmonella* (Satkeeva et al., 2024). Another important way to combat salmonellosis in animals is the use of specialized feed additives in their diet, which enhance immunity and reduce the disease transmission (Davies & Wray, 1997; Petrusha et al., 2022).

***Feeds*:** Birds, cattle, fish and other farm animals receive nutrition through feed, and their health directly depends on the safety of the raw materials from which the feed product is made. The presence of salmonella in feed can lead to the spread of infection on farms, worsening animal husbandry conditions and causing a decrease in production, while increasing the risk of transmission of bacteria to future offspring. The detection of pathogens helps to take timely measures to destroy them or treat feed to eliminate infection, thereby contributing to the protection of animal and human health. As part of studies of microbiological contamination of farm animal feed (Davies & Wray, 1997), a systematic analysis of publications reflecting the prevalence of *Salmonella* bacteria in animal feed was carried out. Special attention is paid to the identification of the predominant *Salmonella* serotypes found both in feed raw materials and on the technological surfaces of milling equipment, as well as in final feed products.

***Causes*:** The leading factor in the microbiological contamination of the production environment and technological equipment at feed production enterprises is the use of raw materials contaminated with pathogenic microorganisms. Numerous studies (Petrusha et al., 2022; Shadrova et al., 2022; Bocharova et al., 2025) indicate a high prevalence of *Salmonella* bacteria in various types of feed materials, from plant components (cereals, meal) to animal products (meat and bone meal, fish meal). In this regard, for safety, it is necessary to consider all ingredients as a possible source of infection in advance and create a multi-stage control system containing:

- primary microbiological monitoring of raw materials;
- preventive treatment technologies' application (e.g., acid preservation);
- implementation of the HACCP system with an emphasis on critical control points.

Of particular epidemiological importance is the unique resistance of *Salmonella* in lipid-containing matrices with low water activity, where they exhibit increased thermal tolerance. Studies have shown that under such conditions, up to 15% of bacterial cells can remain viable after standard heat treatment (85°C, 2 min). Upon subsequent exposure to favorable conditions (temperature 25-37 °C, relative humidity >70%), the metabolism of microorganisms is reactivated, followed by the formation of polysaccharide biofilms on the equipment (Davies & Wray, 1997).

Also, in their forward-looking research, scientists have established that technological dust accumulating on the surfaces of equipment and elements of the production infrastructure of feed enterprises is a unique biomarker that reliably reflects the microbiological status of processed materials. Scientists (Filatov et al., 2017) have developed and patented a complex feed adjuvant designed to prevent bacterial transmission of representatives of the genus *Salmonella* in farm birds (*Gallus gallus domesticus*). The developed feed additive reduces the frequency of *Salmonella* spp release. in cloacal flushes by 42-67%, reduces intestinal colonization by 1.5-2.2 log10 CFU/g (Petrusha et al., 2022). The development and patenting of new feed additives is a strategically important area combining the achievements of veterinary science, biotechnology and practical animal husbandry. These innovations directly contribute to ensuring food security, economic stability of agricultural enterprises and reducing the environmental burden from animal husbandry.

***Control measures*:** Salmonellosis remains one of the key problems in animal husbandry, as contaminated feed is the main source of transmission of *Salmonella spp.* bacteria. Various methods are used to control and prevent salmonellosis. Nanotechnological approaches, including the use of nanoemulsions of essential oils (oregano, thyme) and silver or zinc oxide nanoparticles. Research by scientists from the Orenburg State Agrarian University (Muckey et al., 2022) has shown that nanoforms can reduce the minimum effective concentration of pathogens by 3-5 times compared to traditional forms. The mechanism of action is that nanoparticles damage the bacterial membrane and generate reactive oxygen species, while essential oils disrupt the metabolism of the pathogen. The enzyme is a new generation of probiotic complexes (Mishra et al., 2024) that combine *Bacillus subtilis* with specific enzymes (lysozyme, lactoperoxidase). Such complexes provide up to 78% reduction in *Salmonella* contamination in feed and prevent the formation of biofilms. The study was aimed at a comparative analysis of the effectiveness of liquid and dry disinfectants against *Salmonella Typhimurium*, a contaminating surface of feed production equipment. The results of the study demonstrated significant differences in the antimicrobial activity of different types of disinfectants. Liquid disinfectants have shown the greatest effectiveness. In particular, preparations based on hydrogen peroxide (5-7%) and chlorine-containing compounds (500-1000 ppm) provided a reduction in bacterial load by 4-5 log CFU/cm^2 with an exposure time of 10-15 minutes. At the same time, dry acid mixtures containing formic acid or propionic acid demonstrated moderate antimicrobial activity (2-3 log CFU/cm^2), but their use was especially effective for treating hard-to-reach areas of equipment (Mishra et al., 2024). Biosensory monitoring systems based on aptamers or phage receptors that allow real-time monitoring of feed contamination. Such systems are integrated with IoT-platforms for automatic quality control (Russo & Narayan, 2025). Recent advances in biosensor technologies have revolutionized quality control in animal feed production: the research team has developed innovative biosensor systems capable of continuous monitoring of microbial contamination of feed production lines in real time (Russo & Narayan, 2025). This study (Russo & Narayan, 2025) forms a fundamentally new approach to the organization of intelligent feed safety control systems, integrating innovative biotechnological developments with the digital infrastructure of the fourth industrial revolution. According to the authors, the developed platform has significant scaling potential and demonstrates full compatibility with current international HACCP standards, which opens up prospects for its adaptation to the detection of a wide range of contaminants other than salmonella. Development of effective methods for the control of *Salmonella spp*. Animal feed is a critically important area in ensuring the biosafety of animal husbandry. Recent studies confirm that up to 40% of cases of salmonellosis in farm animals are associated with contaminated feed, which requires a systematic approach to prevention.

DISCUSSION

A review of numerous studies shows the widespread use of antibiotics in the fight against *Salmonella* (Khmyrov A.V. et al., 2013; Nasonkina & Markin, 2017; Litvinova, 2022). Despite its effectiveness, the development of antibiotic resistance is a serious and global problem (Litvinova, 2022). Therefore, the search for alternative ways to combat *Salmonella* remains an urgent problem. One of the promising ways to combat *Salmonella* is the use of feed additives that enhance immunity and reduce the spread of *Salmonella* (Filatov et al., 2017). It is worth noting that to date, a large number of studies are aimed at combating salmonellosis in farm animals, in particular, birds (Filatov et al., 2017). However, there is insufficient research on the use of feed additives in the diet of aquaculture facilities. Considering that aquaculture facilities are carriers of this pathogen, and living in water, they pose a danger both for spreading to other species of aquatic organisms, and for spreading *Salmonella* along with water to food facilities, soil, feed components (for example, fish meal made from fish contaminated with *Salmonella* and insufficiently processed) and other animals. Consideration of each of the four main sources of the spread of salmonellosis separately revealed a certain relationship and cyclicity of the spread of *Salmonella* in the environment. Figure 1 shows a diagram of the cyclical spread of salmonellosis.

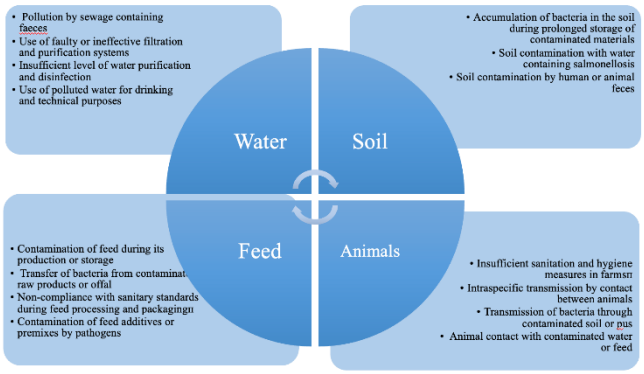
• Pollution by sewage containing faeces
• Use of faulty or ineffective filtration and purification systems
• Insufficient level of water purification and disinfection
• Use of polluted water for drinking and technical purposes
Water
• Accumulation of bacteria in the soil during prolonged storage of contaminated materials
• Soil contamination with water containing salmonellosis
• Soil contamination by human or animal feces
Soil
• Contamination of feed during its production or storage
• Transfer of bacteria from contaminat raw products or offal
• Non-compliance with sanitary standards during feed processing and packaging
• Contamination of feed additives or premixes by pathogens
Feed
• Insufficient sanitation and hygiene measures in farms
• Intraspecific transmission by contact between animals
• Transmission of bacteria through contaminated soil or pus
• Animal contact with contaminated water or feed
Animals

Figure 1. The scheme of cyclical spread of salmonellosis.

The cyclical spread of salmonellosis among water, soil, feed, and farm animals is due to their interconnectedness and the ability of the pathogen to persist and spread in various environments. It is important to work on each stage of the cycle: ensuring sanitary conditions, proper feed and water treatment, and monitoring animal and environmental hygiene and the use of feed additives for disease prevention. This helps to break the bacterial transmission chain, reduce

morbidity and prevent large-scale epidemics. Understanding the importance of working at each stage of the cycle is necessary for a systematic approach to the prevention and control of salmonellosis in agriculture.

***Conclusion*:** Salmonellosis poses a serious threat not only to farm animals, but also to food safety and public health. Infected animals become a source of pathogenic bacteria that can enter food products – meat, milk, eggs. This creates a risk of human infection and requires a comprehensive approach to prevention.

Effective counteraction to salmonellosis includes several important areas. First of all, strict observance of sanitary and hygienic standards in livestock farms is necessary. Regular disinfection of premises, inventory and equipment helps to destroy pathogens and prevent their spread. Particular attention should be paid to the quality of feed and water, as they often become transmission routes. The analysis of modern scientific publications and studies devoted to the study of the epidemiology of salmonellosis allows us to state the relevance of this problem. The spread of *Salmonella spp*. poses a serious epidemiological threat that requires a comprehensive study of transmission mechanisms and the development of effective preventive measures. Key aspects of the problem include:

The cyclical nature of the epidemic process associated with: seasonal factors (peak incidence in the summer and autumn period); peculiarities of production cycles in animal husbandry and the food industry. Ecological plasticity of the pathogen: farm animals (up to 40% of cases of infection); aquatic ecosystems (when using untreated wastewater); food products (meat, eggs, milk, vegetables); soil (in case of infection with faecal matter). The need to optimize control: improvement of microbiological monitoring methods; implementation of molecular and genetic detection methods (real-time PCR, MALDI-TOF MS); development of preventive measures at all stages of the food chain. Development of preventive animal feed: inclusion of probiotic strains (*Bacillus subtilis, Lactobacillus spp.*) with proven antagonistic activity, as well as postbiotics – bacteriocins, which are independent of temperatures and have a high shelf life of their properties; the use of organic acids (formic acid, propionic acid) to control intestinal pH; addition of phytogenic components (essential oils of oregano, thyme) with antimicrobial effect. Special attention should be paid to studying the pathogenicity factors of *Salmonella spp*. and the mechanisms of antibiotic resistance formation, which is of fundamental importance for predicting epidemiological risks. Modern research demonstrates the need for an interdisciplinary approach combining advances in epidemiology, microbiology, and food safety.

***CRediT author statement*:** Ekaterina Kosolapova wrote this article, Tatiana Maltseva has contributed to the development of the concept and data collection, Anastasiya Olshevskaya analyzed data; Victoria Shevchenko, Tatiana Dmitrienko contributed to the methodology, Igor Martynyuk was engaged in processing of the results. All authors made equal contribution to this article.

***Conflict of interest*:** The authors declare no conflict of interest.

***Ethical statement*:** This article does not contain any studies which require ethics committee approval.

***Availability of data*:** The data is available with the corresponding author which can be made available on request.

***Consent to participate*:** All participants consented for this research study.

***Informed consent*:** The participants signed informed consent regarding publishing their data and photographs.

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***SDGs addressed*:** Zero hunger; Clean water and sanitation; Good Health and Well-being; Decent Work and Economic Growth

***Policy referred*:** Codex Alimentarius (FAO/WHO); World Health Organization (WHO) Global Foodborne Infections Network; WHO Global Action Plan on AMR

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